VEHICLE SYSTEMS PANEL

CO-CHAIRMAN

T. BALES - LaRC
T. MODLIN - JSC

EXPENDABLE LAUNCH VEHICLES & CRYOTANKS

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REUSABLE VEHICLES

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D. HERBENER - MMC
E. NIELSEN (WJSA) - RAPPORTEUR

VEHICLE SYSTEMS - EXPENDABLE

INTRODUCTION

PERSPECTIVES OF THE SUBPANEL ON EXPENDABLE LAUNCH VEHICLE STRUCTURES AND CRYOTANKS

- NEW MATERIALS PROVIDE THE PRIMARY WEIGHT SAVINGS EFFECT ON VEHICLE MASS/SIZE
  - PROVIDE ROBUSTNESS IN DESIGN
  - YIELD SYSTEMS COST SAVINGS

- TODAY'S INVESTMENT
  - DISPROPORTIONATELY SMALL
  - SIGNIFICANT BENEFITS APPARENT
  - NO FOCUSED PROGRAMS IN MATERIALS AND STRUCTURES TECHNOLOGIES WITHIN NASA FOR LAUNCH VEHICLES

- TYPICALLY 10-20 YEARS TO MATURE AND FULLY CHARACTERIZE NEW MATERIALS
  - MANUFACTURING PROCESSES MUST BE DEVELOPED CONCURRENTLY
  - USER NEEDS CAN ACCELERATE MATERIALS DEVELOPMENT
  - SELECTED EXAMPLES (8090, 2219, 7XXX)
VEHICLE SYSTEMS

TECHNOLOGY NEEDS ADDRESSED BY THE EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS SUBPANEL

- MATERIALS DEVELOPMENT
  - ADVANCED METALLICS
  - COMPOSITES
  - TPS/INSULATION

- MANUFACTURING TECHNOLOGY
  - NEAR NET-SHAPE METALS TECHNOLOGY
  - COMPOSITES
  - WELDING

- NDE
## EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
### VEHICLE SYSTEMS PANEL

<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES &amp; RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Advanced structural materials</td>
<td></td>
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<table>
<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• In the last 10 years, many novel materials have been discovered that have applicability to space programs</td>
<td>• Evaluate the application areas and state of maturity of these new materials</td>
</tr>
<tr>
<td>• These include but are not limited to:</td>
<td>• Design and analytical tool to realistically calculate cost and weight benefits arising from incorporation of such materials</td>
</tr>
<tr>
<td>• Ultra lightweight alloys</td>
<td>• Prioritize and select for funding the several materials that offer the most significant pay-off in the 3-10 year time frame</td>
</tr>
<tr>
<td>• Metal matrix composites</td>
<td>• Insist on a teaming approach that includes NASA, producers and users and involves selection, design, manufacturing, and engineering criteria</td>
</tr>
<tr>
<td>• Polymer based composites</td>
<td></td>
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<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES &amp; RESOURCE REQUIREMENTS:</th>
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<tr>
<td>• Near net shape fabrication technology for vehicle structures</td>
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<th>BACKGROUND &amp; RELATED FACTORS:</th>
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<tr>
<td>• Current vehicle system structures employ conventional materials and fabrication technology</td>
<td>• Initiate aggressive technology development program to demonstrate forming and joining processes suitable for all appropriate vehicle system structures</td>
</tr>
<tr>
<td>• Resultant structures are typically high cost and weight penalties are built into the design</td>
<td>• Identify vehicle structures design concepts and requirements amenable to near net shape processing</td>
</tr>
<tr>
<td>• Numerous near net shape fabrication opportunities exist, employing forming and joining technologies which are recognized, but require development</td>
<td>• Select near net shape processes amenable to vehicle hardware</td>
</tr>
<tr>
<td>• Payoffs will include significant improvements in performance and lower fabrication and total program costs</td>
<td>• Develop candidate hardware program to demonstrate/validate fabrication technology</td>
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## EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

### VEHICLE SYSTEMS PANEL

#### DESCRIPTION:
- NDE OF ADVANCED STRUCTURES

#### MILESTONES & RESOURCE REQUIREMENTS:

#### BACKGROUND & RELATED FACTORS:
- Need automated real-time techniques to reduce cost
- Higher-strength materials need more reliable NDE
- Fracture toughness driven designs require precise flaw identification/detection

#### RECOMMENDED ACTIONS:
- NDE processes to evaluate include:
  - Real-time X-ray
  - Real-time Ultrasonics
  - Acoustic Emission
  - Eddy Current
- Incorporate automation features
- Evaluate built-in sensors for composites

#### DESCRIPTION:
- ALU: TECHNOLOGY

#### MILESTONES & RESOURCE REQUIREMENTS:

#### BACKGROUND & RELATED FACTORS:
- Space programs require unique light weight materials
- Alloys developed for commercial and military aircraft are not directly applicable
- Material producers are not currently planning to independently develop the required launch vehicles' alloys; development will be market/user driven
- Near-term ALU alloys can provide up to 15 percent weight savings; longer-term alloys have potential weight savings up to 30 percent
- ALU alloys provide unique processing options, i.e., superplastic forming
- Lack of code R funding limits effectiveness of bridging program

#### RECOMMENDED ACTIONS:
- Fund government, industry, and producer program to accelerate near-term and far-term ALU development
- Tailor materials development with selected manufacturing processes
BENEFITS OF USING AL-LI ALLOYS FOR CRYOGENIC TANKS

15% tank weight savings due to improved specific properties

<table>
<thead>
<tr>
<th>Material costs</th>
<th>Cost-to-orbit benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.0 M</td>
<td>$100 M</td>
</tr>
<tr>
<td>$4.2 M</td>
<td>$85 M</td>
</tr>
<tr>
<td>+ $3.2 M</td>
<td>- $15 M</td>
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</tbody>
</table>

80% raw material weight savings due to reduced scrap rate (80:20)

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<tr>
<th>Material costs</th>
<th>System costs savings</th>
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<tbody>
<tr>
<td>$1.0 M</td>
<td>+ $3.2 M</td>
</tr>
<tr>
<td>$1.0 M</td>
<td>- $15.0 M</td>
</tr>
<tr>
<td>0</td>
<td>- $15.0 M</td>
</tr>
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EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS VEHICLE SYSTEMS PANEL

DESCRIPTION:
- COMPOSITE TECHNOLOGY FOR CRYOTANKS AND DRY BAY STRUCTURES (WITH EMPHASIS ON FIBER REINFORCED PLASTIC SYSTEMS)

MILESTONES & RESOURCE REQUIREMENTS:

BACKGROUND & RELATED FACTORS:
- PROCESSES MUST BE DEFINED TO ACCOUNT FOR FRP MANUFACTURING CAPABILITIES
- A TOTALLY INTEGRATED MATERIALS, DESIGN, MANUFACTURING, INSPECTION, AND TESTING PROCESS MUST BE IDENTIFIED WHICH WILL ACCOUNT FOR THE UNIQUE PROCESS NEEDS AND CAPABILITIES OF COMPOSITES
- WEIGHT REDUCTION POTENTIAL IS 20-30 PERCENT

RECOMMENDED ACTIONS:
- ESTABLISH COMPOSITE CRYOTANK SYSTEM DESIGN REQUIREMENTS. IDENTIFY LINER REQUIREMENTS
- DETERMINE STATE-OF-THE-ART ABILITIES IN FRP COMPOSITES FOR MATERIALS, DESIGN, MANUFACTURING, INSPECTION AND TESTING. SPECIFICALLY CONSIDER THE FOLLOWING:
  - IN-LINE INSPECTION
  - IN-SITU CURE METHODOLOGY
  - TOOLING APPROACH
  - JOINING TECHNOLOGY
  - COMPOSITE DAMAGE TOLERANCE AND REPAIR
- DESIGN A BASELINE CRYOTANK
- CONDUCT MANUFACTURING PROCESS TRADES
- ESTABLISH A BASELINE MANUFACTURING PROCESS
- DEFINE FACILITY SIZE REQUIRED TO SUPPORT FRP
MATERIALS AND STRUCTURES TECHNOLOGY FOR SPACE TRANSFER VEHICLES

**Cryotank**
- Materials
  - Al-Li
  - SiCp/Al MMC
  - Ti
  - RMC
- Low cost fabrication
  - Spun formed domes
  - SPF, Built-up structure
  - Filament wound RMC tanks
  - Explosively formed components

**Core primary structure**
- Materials
  - Al-Li
  - B/Al MMC
  - Gr/E
- NDE/durable materials
  - Real time radiography
  - Advanced ultrasonics
  - Space hardened materials
  - Protective coatings/platins

**Benefits**
- Advanced materials: 20-30% weight savings, Increased payload, Greater range
- Low cost fabrication: 30% cost savings, Reduced assembly time
- NDE/durable materials: Increased reliability and vehicle life

EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS
VEHICLE SYSTEMS PANEL

**DESCRIPTION:**
- WELDING
  - PROCESS UNDERSTANDING, OPTIMIZATION, AND AUTOMATION FOR JOINING STRUCTURES

**MILESTONES & RESOURCE REQUIREMENTS:**

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<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
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<tbody>
<tr>
<td>WELDING USED AS JOINING TECHNIQUE ON ALL MAJOR AEROSPACE HARDWARE</td>
</tr>
<tr>
<td>REPAIR OF WELDING DEFECTS MAJOR COST IN MANUFACTURING</td>
</tr>
<tr>
<td>HUMAN ERRORS A MAJOR CAUSE OF WELDING DEFECTS</td>
</tr>
<tr>
<td>LACK OF UNDERSTANDING OF PROCESS VARIABLES AND THEIR INFLUENCE ON PROPERTIES</td>
</tr>
<tr>
<td>AUTOMATION POTENTIALLY CAN REDUCE NDE</td>
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<th>RECOMMENDED ACTIONS:</th>
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<tbody>
<tr>
<td>IDENTIFY PROCESS VARIABLES RELATIONSHIPS</td>
</tr>
<tr>
<td>DEVELOP PROCESS MODELS</td>
</tr>
<tr>
<td>IDENTIFY AND DEVELOP SENSORS FOR PROCESS MONITORING AND FEEDBACK</td>
</tr>
<tr>
<td>IDENTIFY AND DEVELOP CONTROL HARDWARE AND SOFTWARE</td>
</tr>
<tr>
<td>VERIFY AND VALIDATE PROCESSES AND CONTROLS</td>
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### EXPENDABLE LAUNCH VEHICLES AND CRYOTANKS

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<td>• NEAR NET-SHAPE METALS TECHNOLOGY</td>
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<td>- BUILT-UP STRUCTURES FOR CRYOGENIC TANKS AND DRY-BAY APPLICATIONS</td>
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<tr>
<td>• INTEGRALLY STIFFENED STRUCTURES FABRICATED BY MACHINING FROM A THICK PLATE RESULTS IN HIGH SCRAP RATES (85%)</td>
<td>• IDENTIFY VEHICLE STRUCTURES, DESIGN CONCEPTS AND REQUIREMENTS AMENABLE TO BUILT-UP STRUCTURE APPROACH</td>
</tr>
<tr>
<td>• LOW BUY-TO-FLY RATIO REQUIRED FOR ECONOMIC UTILIZATION OF NEW HIGH PERFORMANCE METALS</td>
<td>• DEVELOP FORMING AND JOINING PROCESSES TO FABRICATE APPROPRIATE STRUCTURAL PREFORMS</td>
</tr>
<tr>
<td>• BUILT-UP STRUCTURE APPROACH IS APPLICABLE TO BROAD RANGE OF STRUCTURAL COMPONENTS ENCOMPASSING TANKS AND DRY-BAY STRUCTURES</td>
<td>• DESIGN, FABRICATE AND TEST STRUCTURAL SUBELEMENTS</td>
</tr>
<tr>
<td>• PAYOFFS WILL INCLUDE SIGNIFICANT IMPROVEMENTS IN PERFORMANCE AND LOWER FABRICATION COST</td>
<td>• DEMONSTRATE STRUCTURAL INTEGRITY UNDER REALISTIC SERVICE CONDITIONS</td>
</tr>
<tr>
<td></td>
<td>• VALIDATE TECHNOLOGY THROUGH DESIGN, FABRICATION AND TESTING OF FULL-SCALE TANKS AND DRY-BAY STRUCTURAL ARTICLES</td>
</tr>
</tbody>
</table>

### SUMMARY OF THE DELIBERATIONS OF THE EXPENDABLE LAUNCH AND CRYOTANKS SUBPANEL

- THE MAJOR NEAR TERM ISSUE FOR AL-LI IS WHETHER FUNDING WILL BE PROVIDED TO ASSURE INCORPORATION IN THE NLS
  - PRODUCTION CAPABILITY IS IN PLACE FOR 8090, WELDALITE, AND 2090
  - NEAR NET SHAPE PROCESSES HAVE BEEN DEFINED AND SCALE UP ACTIVITIES ARE UNDERWAY
  - PROGRAM MANAGEMENT DECISIONS ARE REQUIRED TO EXPLOIT POTENTIAL
- MATERIALS TECHNOLOGY PROGRAMS WITHIN NASA ARE TOO LIMITED/RESTRICTIVE
  - NO FOCUSED PROGRAMS IN MATERIALS AND STRUCTURES TECHNOLOGIES WITHIN NASA FOR LAUNCH VEHICLES
  - CLEAR NEED FOR SUSTAINED/CONTINUING PROGRAMS TO SUPPORT USER NEEDS/LONG TERM NASA MISSIONS
- SIGNIFICANT NEEDS EXIST FOR STRUCTURAL ANALYSIS AND OPTIMIZATION PROGRAMS
- NDE TECHNIQUES AND METHODS MUST BE EXPLOITED TO ASSURE INTEGRITY, RELIABILITY AND COST REDUCTIONS
- JOINING AND BONDING TECHNIQUES AND CONCEPTS MUST BE DEVELOPED AND CHARACTERIZED FOR FUTURE LARGE LAUNCH VEHICLE APPLICATIONS
REUSABLE VEHICLES SUBPANEL
ISSUE/TECHNOLOGY REQUIREMENTS

PERSPECTIVES

• FUTURE VEHICLES REQUIRE LOW COST, HIGH RELIABILITY, ROBUSTNESS, LOW MAINTENANCE, ON-TIME LAUNCH CAPABILITY
• CURRENT TECHNOLOGY GAPS EXIST RELATIVE TO ACCOMPLISHING THE ABOVE GOAL
• MAJOR TECHNOLOGY CATEGORIES
  - MATERIALS
  - STRUCTURAL CONCEPTS
  - FABRICATION/MANUFACTURING
  - DESIGN/ANALYSIS/CERTIFICATION
  - NON-DESTRUCTIVE EVALUATION (NDE)

MAJOR PAYOFF ITEMS

<table>
<thead>
<tr>
<th>MATERIALS</th>
<th>STRUCTURAL CONCEPTS</th>
<th>FABRICATION/ MANUFACTURING</th>
<th>DESIGN/ANALYSIS/CERTIFICATION</th>
<th>NDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPOSITES</td>
<td>NEAR NET SHAPES INTEGRALLY- MACHINED</td>
<td>BOND WELD EXTRUDE FORGING POWDER LIQUID ATOMIZATION</td>
<td>CRITERIA SYSTEMS OPTIMIZATION</td>
<td>DESIGN FOR INSPECTABILITY HEALTH MONITORING</td>
</tr>
<tr>
<td>AI-LI TPS</td>
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DESCRIPTION:

IN SPACE JOINING
- WELDING
- BONDING

MILESTONES & RESOURCE REQUIREMENTS:

RECOMMENDED ACTIONS:

- IDENTIFY AND DEVELOP WELDING AND BONDING PROCESSES FOR IN SPACE USE
- IDENTIFY LIMITING FEATURES OF ARC WELDING PROCESSES FOR USE IN SPACE
- DEVELOP WELDING HARDWARE/SOFTWARE FOR SPACE USE
- IDENTIFY SAFETY ISSUES ASSOCIATED WITH WELDING IN SPACE
- DEVELOP REMOTE CONTROL AND MANIPULATORS FOR OPERATIONS
- PLAN AND CONDUCT PROOF OF EXPERIMENT FOR SHUTTLE FLIGHT

BACKGROUND & RELATED FACTORS:

- REPAIR TECHNIQUES FOR IN SPACE HARDWARE REQUIRED
- IN SPACE ASSEMBLY TECHNIQUES FOR LARGE STRUCTURES
- WELDING AND BONDING PROVIDE HIGH WEIGHT, LEAK PROOF STRUCTURES
- SOVIETS HAVE MADE EMERGENCY WELDING REPAIR ON MIR
- ELECTRON BEAM PROCESS ONLY PROCESS PRESENTLY USED IN VACUUM
<table>
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<td>ISSUE/TECHNOLOGY REQUIREMENTS</td>
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**DESCRIPTION:**
- Damage tolerant design for composite structures

**MILESTONES & RESOURCE REQUIREMENTS:**
- Publish damage tolerant design data book for composite structure

**BACKGROUND & RELATED FACTORS:**
- Space transportation missions are weight driven
- Composites reduce weight, reduce part count and are adaptable to complicated shapes
- Unless properly designed, easily damaged
- Goal: visually inspect only with minimal impact on weight

**RECOMMENDED ACTIONS:**
- Develop damage tolerant philosophy/criteria
- Assemble industry available test data
- Identify candidate fibers, resins, lay-ups, and manufacturing processes for damage tolerant skin designs
- Develop designed experiment utilizing damage tolerant testing to identify drivers (temperature range R.T. to 800°F)
- Utilize best skin designs for honeycomb panels and perform designed experiment to again identify drivers (temperature range R.T. to 800°F)

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**DESCRIPTION:**
- Optimized system engineering approach to ensure robustness

**MILESTONES & RESOURCE REQUIREMENTS:**

**BACKGROUND & RELATED FACTORS:**
- Low margins in the ascent operational envelope increases operational cost
- Maintenance and refurbishment of low-life parts is costly in inspection, analysis and change-out
- Robustness provides lower total cost, less rework, launch time, higher performance and less complex operation

**RECOMMENDED ACTIONS:**
- Develop concurrent engineering tools for flight mechanics, control, performance, leads, aerelasticity, manufacturing, operations, etc...
- Develop inter-disciplinary, total cost optimization and trades analysis tools
- Develop accurate statistical quantification tools for all sensitive parameters
- Develop atmospheric (winds) characteristics for design and operation
- Analytical tools to more accurately predict aerodynamics, plumes, acoustical, etc. induced environment data CFD
- Develop model synthesis tools to reduce model development
- Develop system probabilistic tools to guide optimization criteria
# REUSABLE LAUNCH VEHICLES AND CRYOTANKS
## VEHICLE SYSTEMS PANEL

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<tbody>
<tr>
<td>• MAINTENANCE AND REFURBISHMENT PHILOSOPHY</td>
<td></td>
</tr>
<tr>
<td>BACKGROUNDS &amp; RELATED FACTORS:</td>
<td>RECOMMENDED ACTIONS:</td>
</tr>
<tr>
<td>• CURRENT REUSABLE SPACE VEHICLES ARE ESSENTIALLY DE-CERTIFIED AS FLIGHT VEHICLES AT THE MOMENT OF TOUCHDOWN</td>
<td>• EXAMINE MAINTENANCE AND REFURBISHMENT PHILOSOPHIES OF NON-SPACE VEHICLE OPERATORS TO IDENTIFY &quot;LESSONS LEARNED&quot; FOR SPACE SYSTEMS</td>
</tr>
<tr>
<td>• RE-CERTIFICATION REQUIRES LARGE SCALE DISASSEMBLY, INSPECTION, AND TEST PRIOR TO NEXT FLIGHT</td>
<td>• DEFINE EXPERIENCE DATA BASE FROM PAST REUSABLE VEHICLE FLIGHTS TO ALLOW STATISTICAL CORRELATION OF SYSTEM FAILURE MODES, EFFECTS, AND FREQUENCIES WITH MAINTENANCE AND REFURBISHMENT APPROACHES</td>
</tr>
<tr>
<td>• THESE ACTIVITIES ARE LABOR INTENSIVE AND ACCOUNT FOR A LARGE PART OF THE OPERATIONS COST OF THE VEHICLE.</td>
<td>• DEVELOP CRITERIA TO DESIGN FOR MAINTENANCE AND ASSEMBLY</td>
</tr>
<tr>
<td></td>
<td>• IDENTIFY MAINTENANCE AND REFURBISHMENT REQUIREMENTS FOR PROPOSED VEHICLE TECHNOLOGIES</td>
</tr>
<tr>
<td></td>
<td>• COORDINATE TEST PHILOSOPHY AND STRUCTURAL/DESIGN CRITERIA EFFORTS (I.E., DESIGN FOR ASSEMBLY/REPAIR APPROACHES)</td>
</tr>
</tbody>
</table>

# TECHNOLOGIES

- ADVANCED STRUCTURAL MATERIALS
- AL-Li TECHNOLOGY
- NEAR NET SHAPE FABRICATION TECHNOLOGY FOR VEHICLE STRUCTURES
- NEAR NET SHAPE METALS TECHNOLOGY
- NEAR NET SHAPE EXTRUSIONS FOR STRUCTURAL HARDWARE
- NEAR NET SHAPE: FORGINGS
- NEAR NET SHAPE: SPIN FORGINGS
- WELDING
- IN-SPACE WELDING/JOINING
- COMPOSITES TECHNOLOGY FOR CRYOTANKS AND DRYBAY STRUCTURES
- JOINING TECHNOLOGY FOR COMPOSITE CRYOTANKS
- TOOLING APPROACH FOR MANUFACTURING LARGE DIAMETER CRYOTANKS
- DEVELOP A CURE METHODOLOGY FOR LARGE COMPOSITE CRYOTANKS
- STATE-OF-THE-ART BUCKLING STRUCTURE OPTIMIZER PROGRAM
- STATE-OF-THE-ART "SHELL OF REVOLUTION" ANALYSIS PROGRAM
- NDE FOR ADVANCED STRUCTURES
- IN-LINE INSPECTION OF COMPOSITES
- SCALE-UP OF LAUNCH VEHICLES
- LAUNCH VEHICLE TPS/INSULATION BEYOND 27.5 FT. DIAMETER
- DESIGN & FABRICATION OF THIN WALL CRYOTANKS FOR SPACE EXPLORATION (5-20 FT. DIA.)
7.1.2 Supporting Charts
### REUSABLE VEHICLES SUBPANEL

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<td>• CRYOGENIC TANKAGE</td>
<td>• SUFFICIENT DATA BASE FOR PROGRAM MANAGERS TO ACCEPT THE MATERIAL IN NEW LAUNCH VEHICLE PROGRAMS</td>
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<tr>
<td>• QUALIFY AL-LI TANKAGE</td>
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<tr>
<td>• LIGHTWEIGHT CRYOGENIC TANKS WILL INCREASE THE PAYLOAD TO ORBIT OF VARIOUS LAUNCH SYSTEMS</td>
<td>• CONDUCT A PROGRAM COORDINATED WITH EXISTING PROGRAMS TO ENSURE THAT THE NECESSARY TECHNOLOGY HAS BEEN DEMONSTRATED AND THAT ENGINEERING PROPERTIES INCLUDING ML-HOBK-5 STATISTICALLY DERIVED PARENT MATERIAL AND WELD PROPERTIES, FRACTURE TOUGHNESS, STRESS CORROSION, RESISTANCE, ETC. HAVE BEEN ESTABLISHED</td>
</tr>
<tr>
<td>• AL-LI HAS NOT REACHED THE MATURITY TO INCORPORATE INTO THE DESIGN WITHOUT CONSIDERABLE ADDITIONAL EFFORT BEYOND THAT CURRENTLY FUNDED.</td>
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<tr>
<td>• QUALIFY COMPOSITE TANKAGE FOR USE WITH LIQUID HYDROGEN</td>
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</thead>
<tbody>
<tr>
<td>• GREATER PAYLOAD TO ORBIT CAN BE OBTAINED WITH COMPOSITE TANKS SUITABLE FOR USE WITH LIQUID HYDROGEN</td>
<td>• ESTABLISH THE ENABLING TECHNOLOGY TO BUILD, INSULATE AND TEST A SUB-SCALE TANK. TANK TEST SUCCESSFUL</td>
</tr>
<tr>
<td>• RECENT TESTS WITH A 1/3 FULL SCALE NASP TANK WITH LIQUID NITROGEN (LN2) DEMONSTRATED THAT THE COMPOSITE WAS NOT PERMEABLE AT LN2 TEMPERATURES. EARLIER SMALL SCALE TESTS WITH GASEOUS HELIUM AT -420F DEMONSTRATED TECHNICALLY ACCEPTABLE PERMEABILITY AND RESISTANCE TO MICROCRAKING WHEN THERMALLY CYCLED. NASP 1/3 SCALE TANK IS CURRENTLY IN TEST. THERMAL CYCLE TESTS AND LIQUID HYDROGEN LOADING ARE BEING CONDUCTED.</td>
<td>• IDENTIFY WHERE THE TECHNOLOGY IS ADEQUATE AND WHERE DEVELOPMENT IS REQUIRED</td>
</tr>
<tr>
<td></td>
<td>• DEMONSTRATE ADEQUATE TECHNOLOGY</td>
</tr>
<tr>
<td></td>
<td>• DEVELOP TECHNOLOGY (SUBSCALE)</td>
</tr>
<tr>
<td></td>
<td>• DECIDE ON MANUFACTURING APPROACH</td>
</tr>
<tr>
<td></td>
<td>• DESIGN SUBSCALE TANK WITH ALL THE FEATURES OF A FULL SCALE TANK</td>
</tr>
<tr>
<td></td>
<td>• FABRICATE, INSULATE, INSPECT AND TEST TANK WITH LH2</td>
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</tbody>
</table>

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## REUSABLE VEHICLES SUBPANEL

### VEHICLE SYSTEMS PANEL

### DESCRIPTION:
- Cryogenic Tankage
  - Qualify composite tankage for use with liquid oxygen

### MILESTONES AND RESOURCE REQUIREMENTS:
- Demonstrate the ability to meet safety requirements
- Feasibility program $500K

### BACKGROUND & RELATED FACTORS:
- Greater payload to orbit can be obtained with composite tanks suitable for use with LOX
- Recent tests with a 1/3 full scale NASP tank with liquid nitrogen (L,N) demonstrated that the tank was not permeable (in an engineering sense) at L,N temperatures. NASP 1/3 subscale tank is currently in test. Thermal cycle tests and liquid hydrogen loading are being conducted.

### RECOMMENDED ACTIONS:
- Establish feasibility program with the following as a minimum:
  - Establish set of design ground-rules
  - Develop liners with damage that will prevent a conflagration
  - Tests to demonstrate no conflagration
  - 1000 cycles of rapid O2 pressurization
  - Conduct rapid fill with particle impingement
  - Burst test

### DESCRIPTION:
- Launch vehicle TPS/insulation

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- Clean Air Act mandates elimination of freon blowing agents
- Robust design philosophy dictates durable TPS systems
- Long duration space missions require space qualified TPS materials to survive environment and not create debris for other critical operations

### RECOMMENDED ACTIONS:
- Continue ALSAD to develop alternate blowing agents
- Look beyond near-term fixes to fund long-term replacement materials
- Develop robust/reusable or easily replaceable TPS
<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DURABLE PASSIVE THERMAL CONTROL</td>
<td></td>
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<tr>
<td>DEVICES AND/OR COATINGS</td>
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</tbody>
</table>

**BACKGROUND & RELATED FACTORS:**
- REUSABLE CVT PROGRAM REQUIRES LIGHTWEIGHT DURABLE INSULATION FOR MINIMUM COST AND QUICK TURN AROUND

**RECOMMENDED ACTIONS:**
- DEVELOP ROBUST HIGH PERFORMANCE, LOW COST AND REUSABLE THERMAL CONTROL DEVICES AND/OR COATINGS

<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DEVELOPMENT AND CHARACTERIZATION OF PROCESSING METHODS TO REDUCE ANISOTROPY OF MATERIAL PROPERTIES IN A-LI</td>
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</tbody>
</table>

**BACKGROUND & RELATED FACTORS:**
- DESIGN ALLOWABLES ARE FREQUENTLY DICTATED BY THE S-T STRENGTH (PREVENTING THE ACHIEVEMENT OF MAXIMUM BENEFIT FROM A-LI USE) AND COMMERCIAL AIRCRAFT BUILDERS HAVE HESITATED TO USE A-LI BECAUSE OF CONCERN OVER THE LONG TERM EFFECTS OF ANISOTROPY

**RECOMMENDED ACTIONS:**
- REFINED EXISTING LABORATORY SCALE PROCESS TO PRODUCE ISOTROPIC A-LI
- SUPPORT SCALE-UP OF LAB PROCESS TO PROTOTYPE COMMERCIAL PRODUCTION VOLUMES
- CHARACTERIZE MATERIAL PROTOTYPES OF A-LI PRODUCED BY THESE METHODS
### REUSABLE VEHICLES SUBPANEL

#### VEHICLE SYSTEMS PANEL

<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• DURABLE THERMAL PROTECTION SYSTEM (TPS)</td>
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</table>

<table>
<thead>
<tr>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
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<table>
<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• FUTURE REUSABLE VEHICLE PROGRAMS REQUIRE LIGHTWEIGHT/DURABLE TPS FOR MINIMUM COST AND QUICK TURN AROUND</td>
</tr>
<tr>
<td>• DURABILITY FOR WIND/RAIN AND SERVICING OPERATIONS IS REQUIRED</td>
</tr>
<tr>
<td>• MECHANICALLY ATTACHABLE TPS CAN PROVIDE ACCESS FOR INSPECTION AND REPLACEMENT</td>
</tr>
<tr>
<td>• TPS FOR INTEGRAL LOAD CARRYING CRYOGENIC TANKAGE DOES NOT EXIST</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>RECOMMENDED ACTIONS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• CONTINUE DEVELOPMENT OF DURABLE BOND-ON CERAMIC TILES</td>
</tr>
<tr>
<td>• CONTINUE DEVELOPMENT OF DURABLE MECHANICALLY ATTACHABLE METALLIC AND CERAMIC DESIGNS</td>
</tr>
<tr>
<td>• DEVELOP HIGH TEMPERATURE ADHESIVES FOR BOND-ON DESIGNS</td>
</tr>
<tr>
<td>• DEVELOP SPECIFIC TPS DESIGNS FOR INTEGRAL LOAD CARRYING CRYOGENIC TANKAGE INCLUDING HIGH STRENGTH &amp; TEMPERATURE FOAM INSULATION MAY INVOLVE GROUND PURGE SYSTEM</td>
</tr>
<tr>
<td>• DEMONSTRATE SUITABILITY OF DESIGNS BY FABRICATION AND TESTING TO APPROPRIATE WIND/RAIN, ACOUSTIC, AEROPRESSURE, THERMAL REQUIREMENTS</td>
</tr>
</tbody>
</table>

### DESCRIPTION:

• UNPRESSURIZED ALUMINUM STRUCTURES (INTERSTAGES, THRUST STRUCTURES)
  - QUALIFY ALU FOR USE WITH UNPRESSURED VEHICLE AND STABILITY LIMITED STRUCTURES

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<thead>
<tr>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
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<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
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<tbody>
<tr>
<td>• MAJOR PORTIONS OF VEHICLE STRUCTURES ARE STABILITY LIMITED. THESE INCLUDE COMPRESSION AND BENDING LOADED STRUCTURES. ALUMINUM ALLOYS OFFER INCREASED SPECIFIC STIFFNESS OF 20-40% OVER CURRENT ALUMINUM ALLOYS, WITH THE POTENTIAL FOR CORRESPONDING WEIGHT SAVINGS IN THESE STRUCTURES</td>
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<tr>
<th>RECOMMENDED ACTIONS:</th>
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</thead>
<tbody>
<tr>
<td>• FUND DEVELOPMENT AND TESTING OF DEMONSTRATION OF STABILITY LIMITED STRUCTURES (THRUST STRUCTURES, INTERTANK CONNECTORS, WING BOXES)</td>
</tr>
<tr>
<td>• COORDINATE WITH LOW COST MANUFACTURING AND NEAR NET SHAPE ACTIVITIES</td>
</tr>
</tbody>
</table>

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### REUSABLE VEHICLES SUBPANEL

#### VEHICLE SYSTEMS PANEL

<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
</table>
| • NEAR NET SHAPE SECTIONS  
  - EXTRUSIONS  
  - FORGINGS | |

<table>
<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
</tr>
</thead>
</table>
| • COST OF SCRAP METAL ON INTEGRALLY MACHINED HARDWARE IS NOT COST EFFECTIVE FOR NEWER METAL ALLOYS  
  • RECENT ADVANCES IN ROLL FORGING AND INCREMENTAL FORGING OFFERS SIGNIFICANT MATERIAL COST AND PART COUNT REDUCTIONS FOR LAUNCH VEHICLES  
  • PROCESS PARAMETERS NEED TO BE DEVELOPED FOR EACH NEW ALLOY | • IDENTIFY CANDIDATE HARDWARE FOR LARGE EXTRUSIONS, ROLL AND INCREMENTAL FORGING PROCESSES  
  • DEVELOP CANDIDATE HARDWARE TO DEMONSTRATE VALIDATE FABRICATION TECHNOLOGY  
  • GENERATE DESIGN ALLOWABLES |

### PRESSURIZED STRUCTURES

<table>
<thead>
<tr>
<th>DESCRIPTION:</th>
<th>MILESTONES AND RESOURCE REQUIREMENTS:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• PRESSURIZED STRUCTURES</td>
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<table>
<thead>
<tr>
<th>BACKGROUND &amp; RELATED FACTORS:</th>
<th>RECOMMENDED ACTIONS:</th>
</tr>
</thead>
</table>
| • PRESSURIZED STRUCTURES COMMONLY USED AS CREW COMPARTMENTS ON SHUTTLE AND SPACE STATION ARE CURRENTLY FABRICATED FROM CONVENTIONAL MATERIALS  
  • NEW APPLICATIONS SUCH AS NASP, SSTO, AND MTV WILL HAVE GREATER DEMANDS TO REDUCE WEIGHT WHILE BEING SUBJECTED TO HARSHER ENVIRONMENTS  
  • ADVANCED MATERIALS SUCH AS AH-J AND/ OR COMPOSITES HAVE PROPERTIES CONDUCIVE TO THE ABOVE REQUIREMENTS. INTEGRAL SKIN AND STRINGER, SANDWICH PANELS, ETC., ARE ALL DESIGNS WHERE THESE MATERIALS WOULD PROVE ADVANTAGEOUS | • CONTINUE DEVELOPMENT OF DESIGN CRITERIA FOR THESE STRUCTURES  
  • CONDUCT DEVELOPMENT TESTS TO DETERMINE THE APPLICABILITY OF THESE MATERIALS TO MEET THE REQUIREMENTS  
  • DESIGN AND FABRICATE TEST ARTICLES TO VERIFY THE APPROACH |
### REUSABLE VEHICLES SUBPANEL
**VEHICLE SYSTEMS PANEL**

#### DESCRIPTION:
- **WELDING AND JOINING**
  - Process understanding, optimization, and automation for joining structures

#### MILESTONES AND RESOURCE REQUIREMENTS:

#### BACKGROUND & RELATED FACTORS:
- Repair of welding defects major cost in manufacturing
- Human errors a major cause of welding defects
- Lack of understanding of process variables and their influence on properties
- Welding used as joining technique on all major aerospace hardware
- Automation potentially can reduce NDE

#### RECOMMENDED ACTIONS:
- Identify process variables relationships
- Develop process models
- Identify and develop sensors for process monitoring and feedback
- Identify and develop control hardware and software
- Verify and validate processes and controls
- Development of telerobotic capability for on-orbit repair/maintenance/inspection

---

#### DESCRIPTION:
- **MICROMETEOROID AND DEBRIS HYPERVELOCITY SHIELDS**

#### MILESTONES AND RESOURCE REQUIREMENTS:

#### BACKGROUND & RELATED FACTORS:
- The threat to space vehicles from orbital debris has been rapidly increasing
- Current aluminum double-bumper shielding is very heavy and newer systems such as Nextel have not been qualified

#### RECOMMENDED ACTIONS:
- Develop and qualify lightweight shields and attachment techniques
- Conduct a program to evaluate lightweight shielding designs to meet the threat requirements
- Establish and verify analytical models. Goal is to minimize secondary ejection as well as develop and qualify an ultra-lightweight shielding design

---

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## Description:
- **State-of-the-art shell buckling structure optimizer program to serve as a rapid design tool.**

## Background & Related Factors:
- **Current emphasis on development of large complicated finite element programs suited to detailed analysis, not design optimization.**
- **Available codes are out of date, not comprehensive and user unfriendly.**
- **Will improve the quality and speed of both preliminary design and detailed design.**

## Milestones and Resource Requirements:

## Recommended Actions:
- **Provide following features:**
  - Macintosh or Windows user interface with graphic displays and pull-down menus.
  - Simple user format designed for use by both design and analysis disciplines.
  - Complete library of stiffened shell configurations.

---

## Description:
- **Test philosophy:**
  - Restrict structural test to a load factor that allows alternate usages of expensive hardware.
  - No test factor.

## Background & Related Factors:
- **Hardware has been tested to destruction or yield to the point where it is unusable for other applications.**
- **Structures of advanced materials present significant cost to programs.**
- **"No test factor" may be used as an alternate where weight may not be critical.**

## Milestones and Resource Requirements:

## Recommended Actions:
- **Develop a test code that restricts test to loads which maximize the structures' "reusability." Independent tests should be conducted that allow for data extrapolation from the lower leads to qualify hardware.**
### REUSABLE VEHICLES SUBPANEL

#### VEHICLE SYSTEMS PANEL

**DESCRIPTION:**
- Reduced load cycle time

**MILESTONES AND RESOURCE REQUIREMENTS:**

**BACKGROUND & RELATED FACTORS:**
- Long turnaround time load cycles greatly increase cost and restricts implementation of needed changes
- Load cycle costs are excessive

**RECOMMENDED ACTIONS:**
- Provide an interdisciplinary loads analysis tool that outputs loads and stress instead of sequential loads and stress analysis
- Develop model synthesis techniques to reduce model development
- Develop an optimized code to reduce computer cost

---

**DESCRIPTION:**
- Structural analysis methods

**MILESTONES AND RESOURCE REQUIREMENTS:**

**BACKGROUND & RELATED FACTORS:**
- Current analysis methods involve analysis being conducted by isolated groups and distributing results to next group in a serial fashion
- Iterations are long and laborious
- Analytical methods, particularly in the area of stability knock down factors, should be reviewed, updated as necessary and formalized

**RECOMMENDED ACTIONS:**
- Develop electronically interfaced, self-checking, aeroelastic, thermal, dynamic, and stress analysis tools that allow rapid iteration and apply the benefits of concurrent engineering
- Review available documentation on stability analysis deriving concurrence on knock down factors to be used in above analysis
- Test as required

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### DESCRIPTION:
- **Optimization of Structural Criteria**

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- Current structural criteria does not allow assessment of vehicle risk as related to load variability, subsystem redundancy and factor of safety.
- Lack of simple probabilistic approach to risk assessment stifles examination of required factor of safety to meet program objectives.
- Current approach is to use F.S. ≥ 1.25 for unmanned and F.S. ≥ 1.4 for manned systems.

### RECOMMENDED ACTIONS:
- Develop simple probabilistic approach with necessary data to derive and justify structural criteria.
- Develop analysis tools to implement structural reliability approach and selection of factors of safety.

### DESCRIPTION:
- Develop an engineering approach to properly trade material and structural concepts selection, fabrication, facilities, and cost (total cost).

### MILESTONES AND RESOURCE REQUIREMENTS:

### BACKGROUND & RELATED FACTORS:
- Structural simplicity reduces assembly cost and operational cost.
- Processing can increase cost, material hardness, and lower margins (sensitivities).
- Total cost is the driver, not just weight.
- Sequential engineering is costly.
- Sequential engineering tends to hide sensitivities and proper trades.

### RECOMMENDED ACTIONS:
- Develop concurrent engineering tools (all disciplines) that properly trade between material, structural concept, fabricating facilities, performance, and operation.
- Develop optimization criteria for total cost.
7.2 PROPULSION SYSTEMS PANEL
7.2.1 Final Presentation